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# Design and Analysis of Machining Fixtures

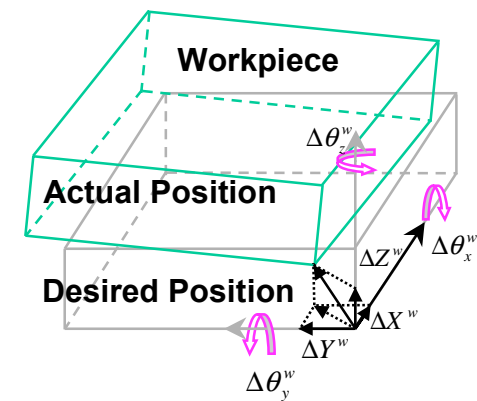
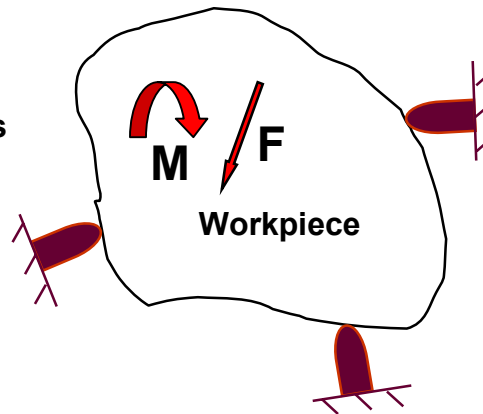
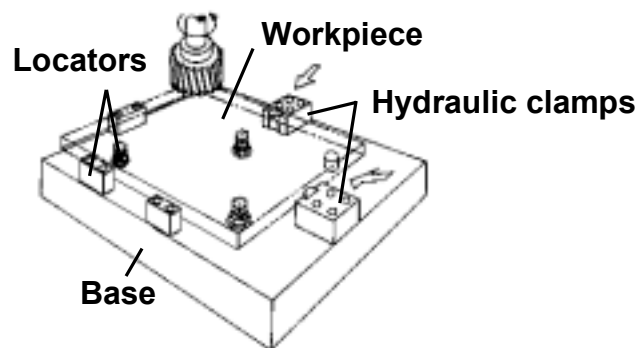
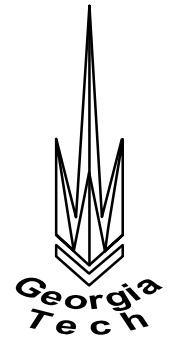
Precision Manufacturing Research Consortium  
Georgia Institute of Technology

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Advisor: Dr. Shreyes N. Melkote

Sponsors: Ford Motor Company, NSF/MTAMRI,  
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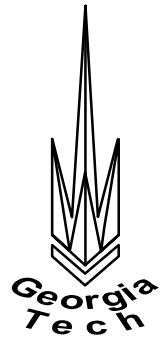
# Introduction



**Workpiece-fixture contact forces and layout play an important role in determining the final part quality.**

# Research on Machining Fixtures

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- **Overall Goal:**

Develop models for analysis and optimal synthesis of fixtures under quasi-static and dynamic conditions.

- **Dedicated Fixtures: for parts of specific shape and size.**

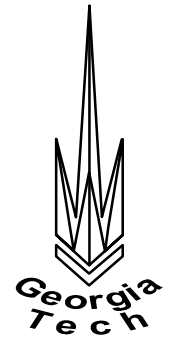
- Quasi-Static Modeling and Analysis
- Dynamic Modeling and Analysis
- Optimal Synthesis

- **Flexible Fixtures: for families of parts with a variety of shapes and sizes.**

- Design Methodology
- Optimal Synthesis
- Modeling and Analysis of Magnetic Chucks

# Dedicated Fixtures

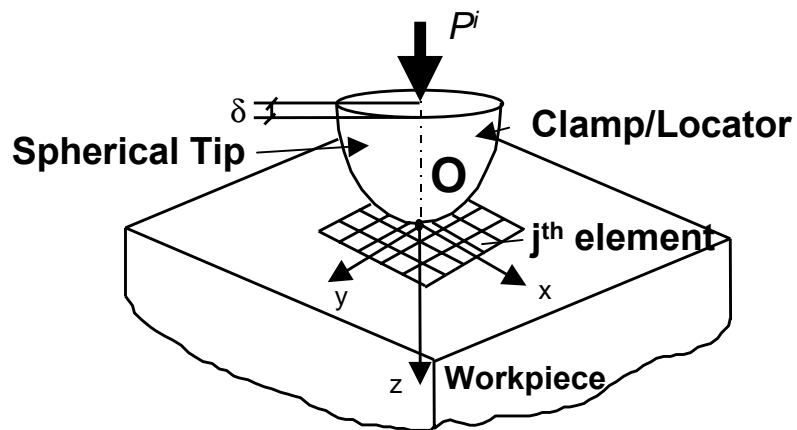
## Quasi-Static Modeling and Analysis



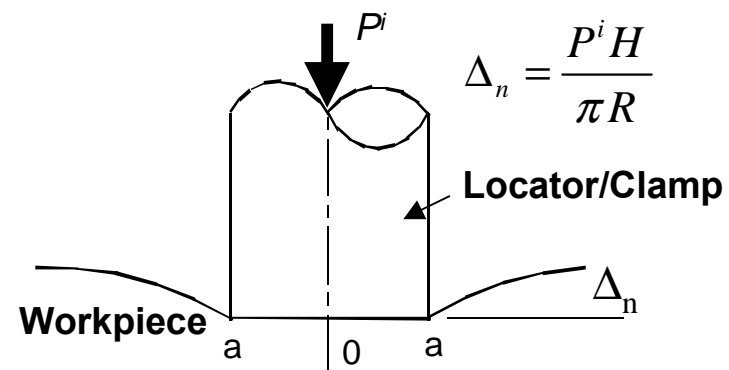
### Objectives:

- Prediction of workpiece-fixture contact forces due to clamping loads.
- Prediction of workpiece rigid body motion due to contact region deformation and its impact on part location accuracy.

### Approach:



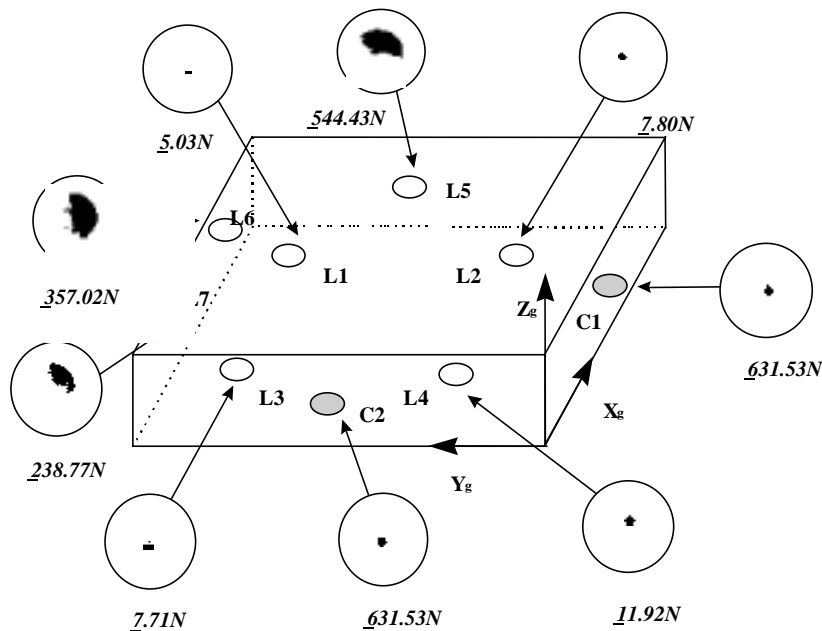
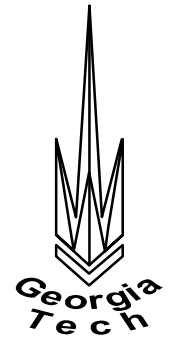
Discretized Contact Model



Closed-Form Contact Elasticity Model

# Quasi-Static Modeling and Analysis

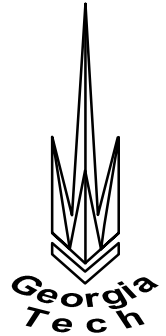
## Measured and Predicted Normal Force Results



Clamping Load		127.2 N			370.6 N			631.5 N		
		Force (N)	Abs. Error	Rel. Error	Force (N)	Abs. Error	Rel. Error	Force (N)	Abs. Error	Rel. Error
L1	Meas.	2.86	0.44	0.15	3.33	0.14	0.04	5.03	0.28	0.06
	Pred.	2.42			3.47			4.75		
L2	Meas.	3.90	0.12	0.03	6.69	1.50	0.22	7.80	1.09	0.14
	Pred.	4.02			5.19			6.71		
L3	Meas.	3.22	0.27	0.08	4.65	0.15	0.03	7.71	0.73	0.09
	Pred.	3.49			4.80			6.98		
L4	Meas.	5.57	1.29	0.23	8.27	0.67	0.08	11.92	1.15	0.10
	Pred.	4.28			7.60			10.77		
L5	Meas.	106.0	2.80	0.03	329.2	19.8	0.06	544.4	9.9	0.02
	Pred.	103.2			309.4			534.5		
L6	Meas.	74.13	7.48	0.10	212.6	12.6	0.06	357.0	16.1	0.05
	Pred.	66.65			200.0			340.9		
L7	Meas.	46.83	3.28	0.07	138.2	7.3	0.05	238.8	11.6	0.05
	Pred.	50.11			130.9			250.4		

**Good agreement between measured and predicted contact forces during clamping. The model is inadequate under dynamic (machining) conditions.**

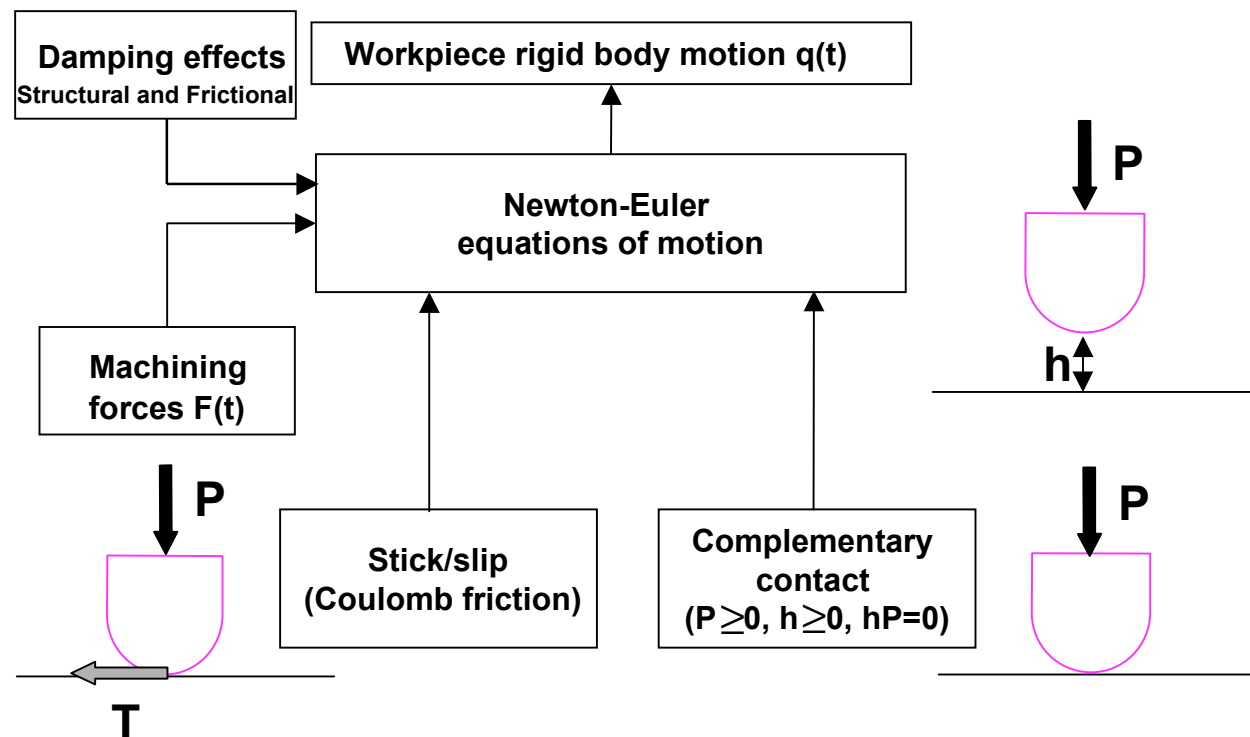
# Dynamic Model Overview



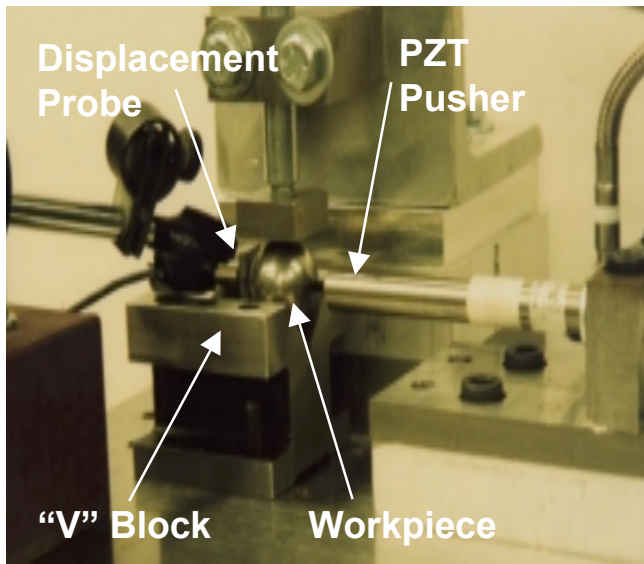
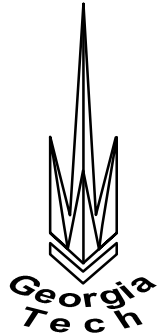
## Objectives:

- Predict contact forces and deformation at each workpiece-fixture contact under dynamic conditions.
- Investigate the workpiece rigid body motion in the fixture and its impact on location accuracy during machining.

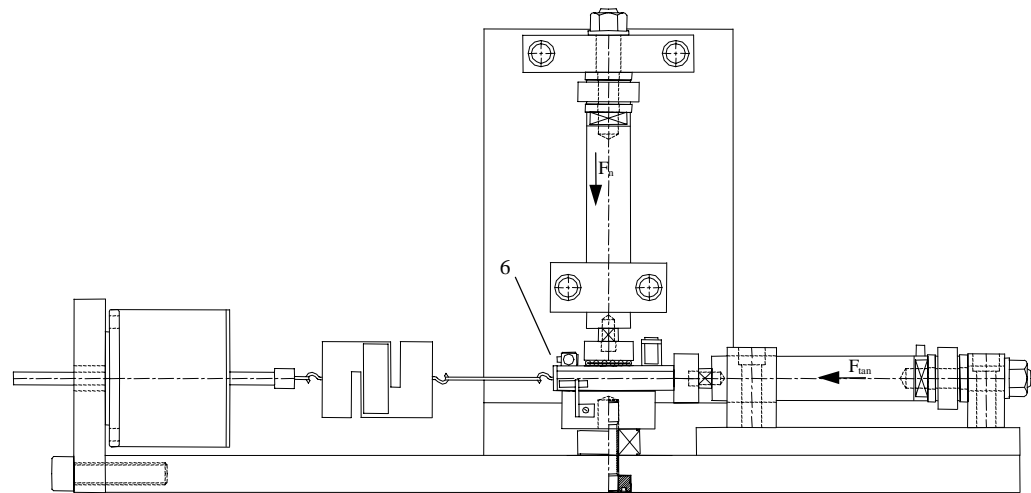
## Approach:



# Dynamic Modeling and Analysis



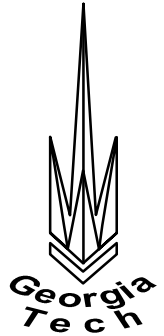
**Experimental Set-Up for Frictional Damping Validation**



**Dynamic Friction Tester  
Oscillatory Normal and Tangential Forces**

# Dynamic Modeling and Analysis

## Validation of Dynamic Fixture-Workpiece Model



#	Sample Material	Normal Force (N)	Tangential Force (N)	Freq. (Hz)	Measured ( $\mu\text{m}$ )	Predicted ( $\mu\text{m}$ )	Abs. Error( $\mu\text{m}$ )
1	Al 2017T-4	269.7	13.9	11.4	3.7	3.9	0.2
2	Al 2017T-4	267.1	13.0	50.0	3.1	3.7	0.6
3	Al 2017T-4	302.7	44.7	11.7	10.2	12.6	2.4
4	Al 2017T-4	301.7	41.5	52.3	8.8	11.7	2.9
5	AISI 302	189.1	15.1	11.4	3.8	4.2	0.4
6	AISI 302	188.4	14.4	50.0	3.8	4.2	0.4
7	AISI 302	229.7	55.4	11.5	11.4	15.0	3.6
8	AISI 302	231.1	54.0	50.9	12.7	15.8	3.1

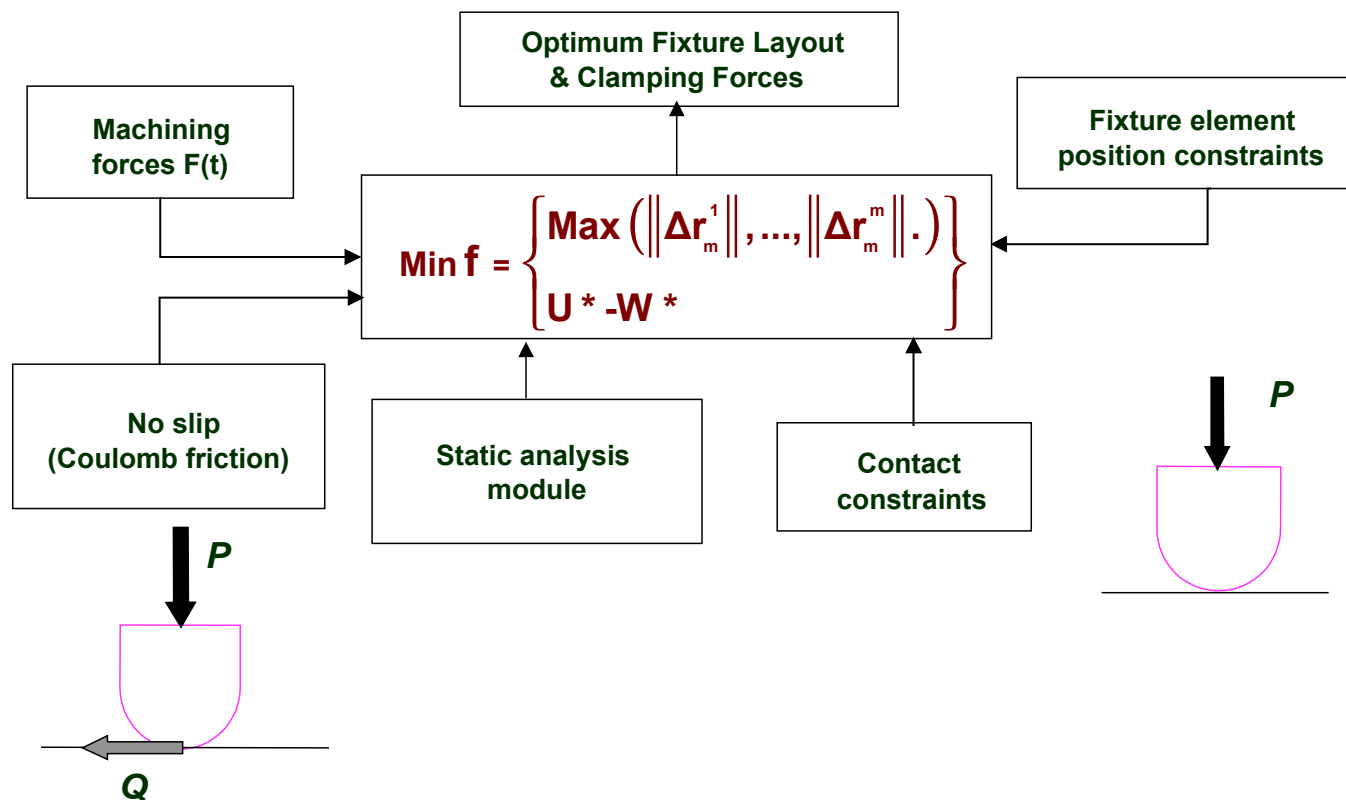


# Optimal Synthesis

## Objectives:

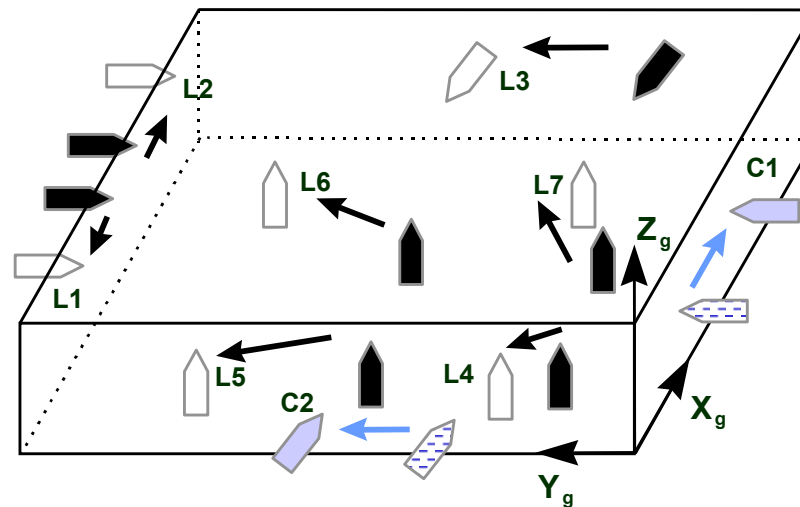
- Minimize workpiece location error at the machining point by optimizing both fixture layout and clamping forces under quasi-static and dynamic conditions.

## Approach:



# Optimal Synthesis

Quasi-Static and Dynamic Loading:



*Initial Locator Position*



*Initial Clamp Position*



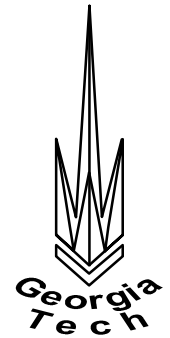
*Optimal Locator Position*



*Optimal Clamp Position*

Effect of the Optimization Procedure on Fixture Layout

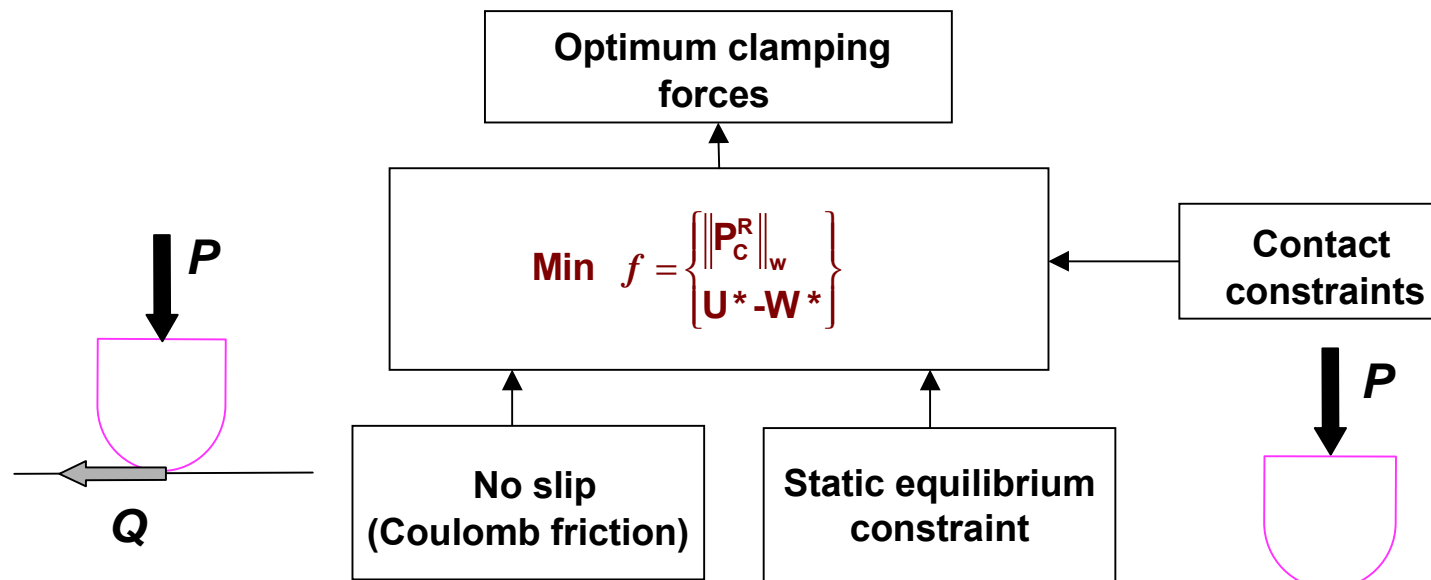
# Clamping Force Optimization



## Objectives:

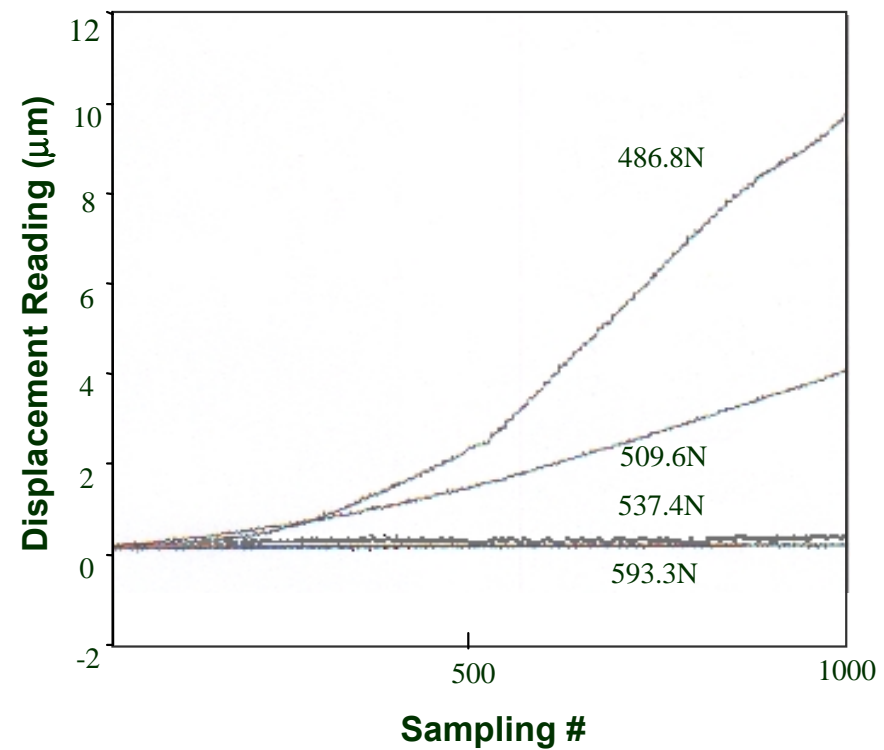
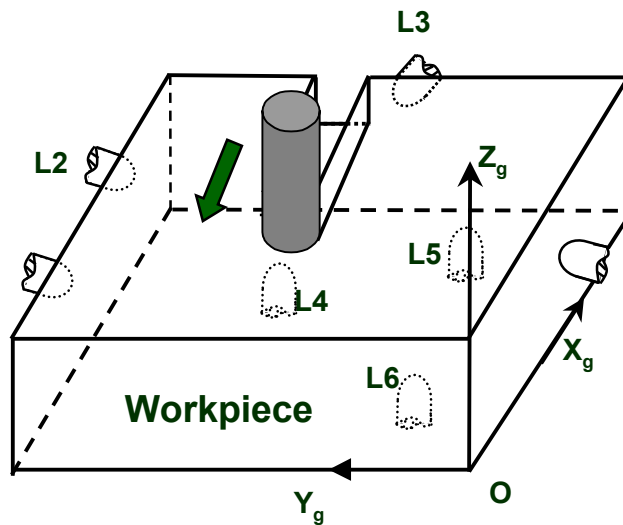
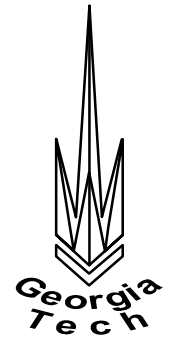
- Search for the minimum clamping forces to restraint the workpiece and minimize workpiece deformation.

## Approach:



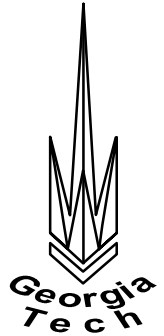
# Clamping Force Optimization

## Experimental Validation



# Clamping Force Optimization

## Experimental Validation

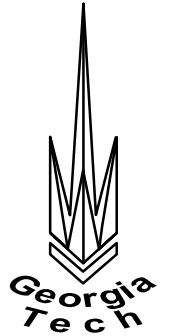


#	Minimal Clamping Force (N)	Applied Clamping Force (N)	Workpiece Displacement	Relative Error (%)
1	512.3	593.3	No slip	
		537.4	No slip	4.7
		509.6	Slip	
		486.8	Slip	
2	638.4	775.8	No slip	
		699.8	No slip	8.8
		676.9	Slip	
		646.5	Slip	

There is good agreement between the predicted and measured optimum clamping forces ( relative error is less than 9%)

# ***Flexible Fixtures***

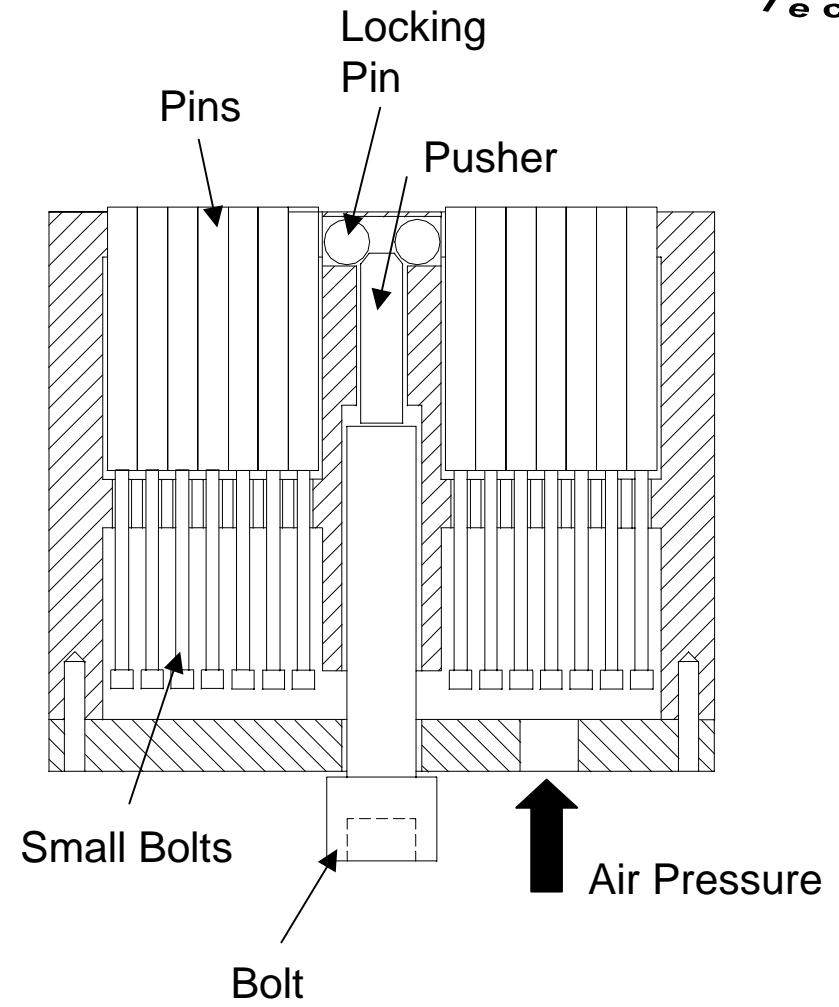
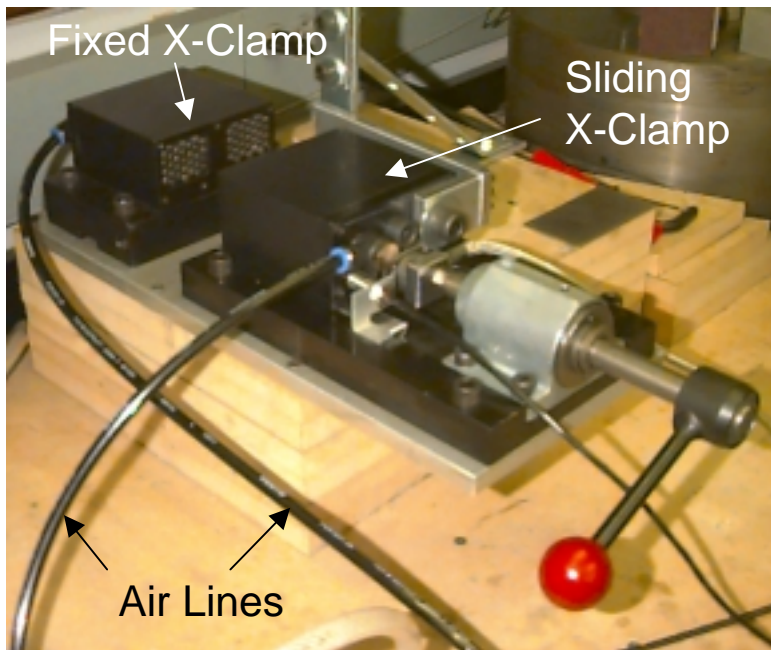
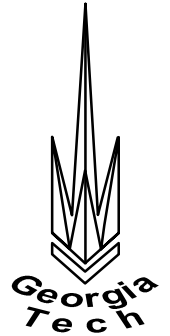
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## ***Objectives:***

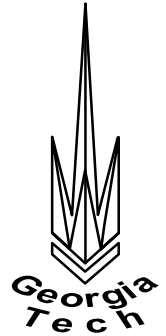
- Design and prototyping of a flexible machining fixture capable of holding a family of parts providing maximum conformability and stiffness.
- Design optimization of a flexible fixture to maximize stiffness, conformability and bound the surface error.

# Matrix<sup>®</sup> X-Clamps



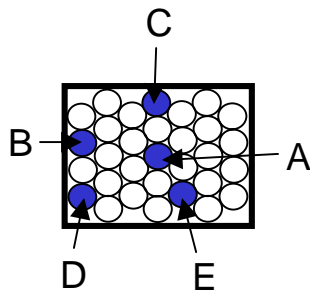
# Experimental Study

## Matrix Bed-of-Nails



### Objectives:

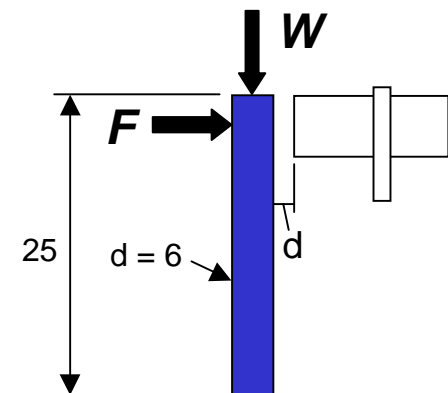
- Measure the maximum force required to overcome the frictional pin locking force,  $W_{max}$
- Measure pin bending stiffness,  $F/d$ .
- Study the effect of workpiece geometry on workpiece-fixture static stiffness.



Pin Position



Workpiece Geometry



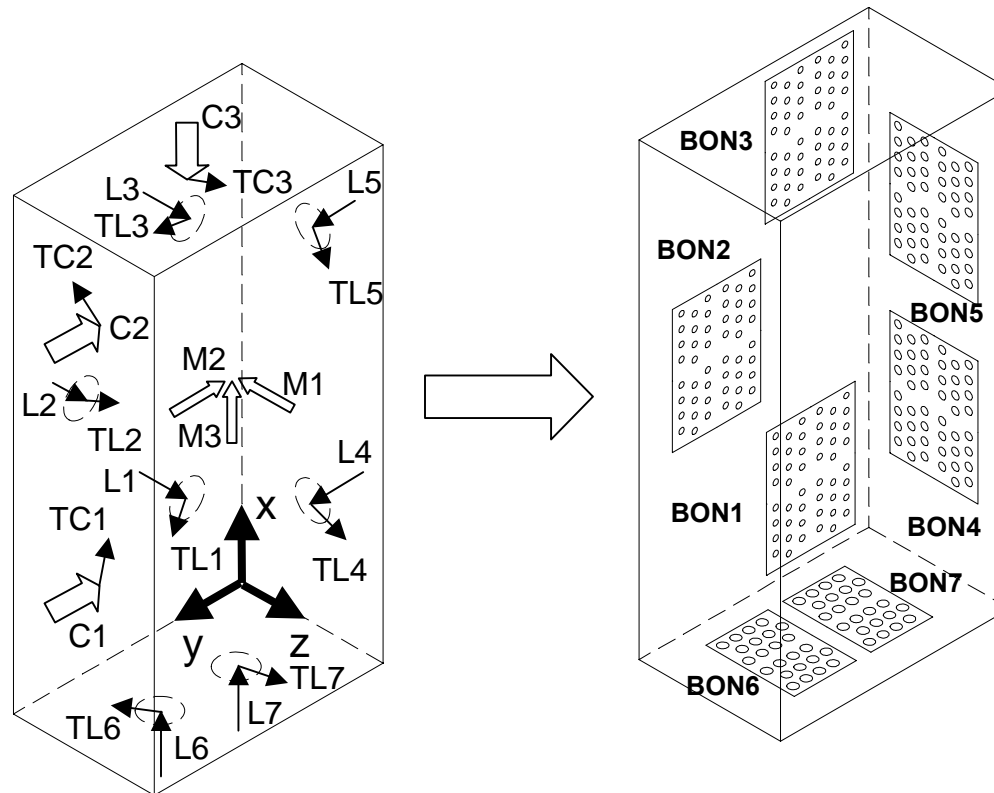
Tangential Stiffness Measurement



# Stiffness Optimization Algorithm

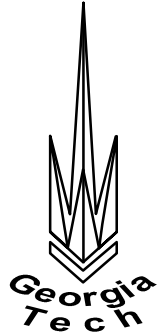
## Objective:

- Finds the optimal BON fixture stiffness in terms of pin diameter, pitch, number of columns and rows to limit the workpiece surface error to a desired value.



# Stiffness Optimization Algorithm

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*Inverse Bed-of-Nails Design Problem:*

**Given:**

Desired workpiece feature error  
due to fixture elastic deformation ( $\epsilon_F$ )



**Output:**

Optimal Fixture  
Stiffness



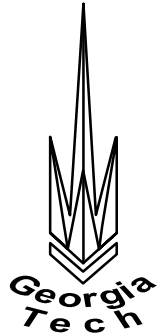
**Output:**

Optimal pin diameter,  
pitch, number of columns  
and rows to achieve  $\epsilon_F$

**General approach that can also be used to optimize the stiffness of dedicated fixtures.**

# Summary

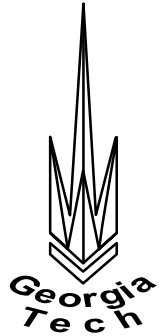
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- Both quasi-static and dynamic models for dedicated machining fixtures were developed to predict workpiece rigid body motion and to optimize fixture layout and clamping forces.
- A stiffness optimization design algorithm for the bed-of-nails fixture was developed to limit the resulting workpiece surface error.
- Experiments have been conducted to characterize a commercially available bed-of-nails fixture.

# *Future Work*

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- Finite Element modeling and verification of fixture-workpiece contacts.
- Development of a design optimization algorithm for the bed-of-nails fixture which incorporates the effect of workpiece geometry on the overall normal and tangential stiffness.
- Investigate high-friction material pairs to maximize the frictional restraint provided by the bed-of-nails fixture.
- Construction of a prototype bed-of-nails fixture for experimental validation of the models developed.

# Discussion